Strain Measurement MEASUREMENT EXPERIMENT

1. OBJECT

The objective of this experiment is to become familiar with the electric resistance strain gage techniques and utilize such gages for the determination of unknown quantities (such as strain and stress) at prescribed conditions of a cantilever beam

2. INTRODUCTION

Experimental stress analysis is an important tool in the design and testing of many products. Several practical techniques are available including photoelastic, coatings and models, brittle coatings, and electrical resistance strain gages.

In this experiment the strain gage will be utilized. There are three steps in obtaining experimental strain measurements using a strain gage:

1. Selecting a strain gage
2. Mounting the gage on the test structure and
3. Measuring strains corresponding to specific loads.

The operation and selection criteria for strain gages will be discussed in this introduction. In this experiment, you will mount a strain gage on a beam and test its accuracy. Measurements will be made with a strain gage rosette in this experiment to obtain the principal stresses and strains on a cantilevered beam.

Strain Gages:

There are many types of strain gages. The fundamental structure of a strain gage consists of a grid-shaped sensing element of thin metallic resistive foil (3 to 6 microns thick) that is sandwiched between a base of thin plastic film (12-16 micron thick) and a covering or lamination of thin film.

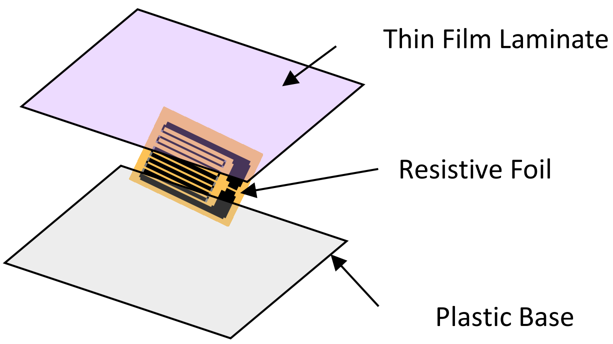


Figure 1: Strain Gage Construction

Strain Gage Operation:

When needed for testing the strain gage is tightly bonded to the structural element under test. This ensures that the sensing element (the metallic resistive foil at the center of the "sandwich") may elongate or contract in the same manner as the strain experienced by the test article. Typically the sensing element is made of a copper-nickel alloy foil. When experiencing a contraction or elongation, most metals undergo a change in electrical resistance. The alloy foil has a rate of resistance change that, with a certain constant, is proportional to the strain. The strain gage is therefore a measuring device that applies the principle of resistance change as a means to effectively sense strain.

3. THEORY

What's a Strain Gage Used For?

The Birdman Contest is an annual event held on Lake Biwa near Kyoto, Japan. In this contest cleverly designed human-powered airplanes and gliders fly several hundred meters across the lake. Aside from the great spectacle of this event, it is a wonderful view of engineering experimentation and competition. Despite the careful designs and well-balanced airframes occasionally the wings of these vehicles fail and crash into the lake. There have been some spectacular crashes but few, if any, injuries to the contestants.

Increasingly, each time a new airplane, automobile, or other vehicle is introduced, the structure of such vehicles is designed to be lighter to attain faster running speeds and less fuel consumption. It is possible to design a lighter and more efficient product by selecting light-weight materials. However, as with all technology, there are plusses and minuses to be balanced. If a structural material is made lighter or thinner the safety of the vehicle is compromised unless the required strength is maintained. By the same token, if only the strength is taken into consideration, the vehicle's weight will increase and its economic feasibility is compromised.

In engineering design the balance between safety and economics is one variable in the equation of creating a successful product. While attempting to design a component or vehicle that provides the appropriate strength it is important to understand the stress borne by the various parts under different conditions. However, there is no technology or test tool that allows **direct** measurement of stress. Thus, strain on the surface is frequently measured in order to determine internal stress. Strain gages are the most common instrument to measure surface strain.

Structural Element of Benicia-Martinez Bridge in Southern California Undergoing a Load Test

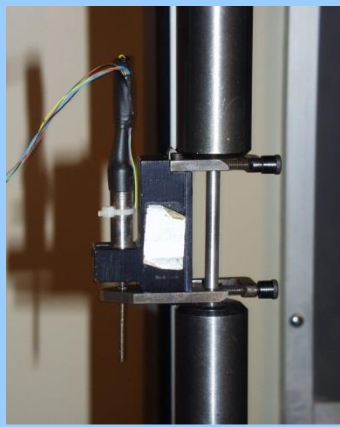
Picture of A Strain Gage Attached to Bridge Element

Strain Measurement

It should be noted that there are various types of strain measuring methods available. These may be roughly classified into mechanical, electrical, and even optical techniques.

From a geometric perspective, strain recorded during any test may be regarded as a distance change between two points on a test article. Thus all techniques are simply a way of measuring this change in distance.

If the elastic modulus of the test article's constituent material is known, strain measurement will allow calculation of stress. As you have learned from your studies and prior labs strain measurement is often performed to determine the stress created in a test article by some external force, rather than to simply gain knowledge of the strain value itself.



This LVDT, attached to a tensile specimen, is also a common tool for measuring strain.

A resistance strain gage consists of a thin strain-sensitive wire mounted on a backing that insulates the wire from the test structure. Strain gages are calibrated with a gage factor F, which relates strain to the resistance change in the wire by

$$F = \frac{\Delta R/R}{\Delta L/L}$$

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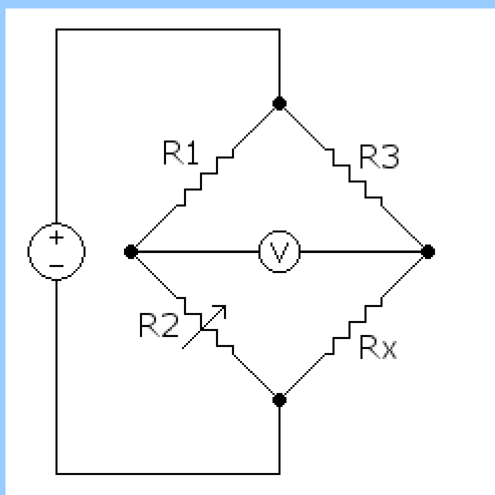
where R is the resistance and L is the length of the wire. The change in resistance corresponding to typical values of strain is usually only a fraction of an ohm

The Wheatstone Bridge

A Wheatstone bridge is a measuring instrument that, despite popular myth, was **not** invented by Sir Charles Wheatstone, but by Samuel H. Christie in 1833. The device was later improved upon and popularized by Wheatstone. The bridge is used to measure an unknown electrical resistance by balancing two legs of a circuit, one leg of which includes the unknown component that is to be measured. The Wheatstone bridge illustrates the concept of a difference measurement, which can be extremely accurate. Variations on the Wheatstone bridge can be used to measure capacitance, inductance, and impedence.

In a typical Wheatstone configuration, Rx is the unknown resistance to be measured; R1, R2 and R3 are resistors of known resistance and the resistance of R2 is adjustable. If the ratio of the two resistances in the known leg (R2/R1) is equal to the ratio of the two in the unknown leg (Rx/R3), then the voltage between the two midpoints will be zero and no current will flow between the midpoints. R2 is varied until this condition is reached. The current direction indicates if R2 is too high or too low.

Detecting zero current can be done to extremely high accuracy. Therefore, if R1, R2 and R3 are known to high precision, then Rx



Typical Wheatstone Bridge diagram with strain gage at Rx

can be measured to high precision. Very small changes in Rx disrupt the balance and are readily detected. Alternatively, if R1, R2, and R3 are known, but R2 is not adjustable, the voltage or current flow through the meter can be used to calculate the value of Rx. This setup is what you will use in strain gage measurements, as it is usually faster to read a voltage level off a meter than to adjust a resistance to zero the voltage.	

Because conventional ohmmeters are not capable of measuring these small changes in resistance accurately, a Wheatstone bridge is usually employed. It can be operated in either a balanced or unbalanced configuration. The configuration for an unbalanced bridge is shown in Figure 3. For an unbalanced bridge, a change in resistance is measured as a non-zero voltage V_o which, can be calibrated in standard strain units (ΔL/L x 10-6) or micro strain. A balanced bridge is rebalanced after each load increment so that the output voltage V_o is zero. The appropriate changes in resistance are then noted and strain calculated using the gage factor.

4. EXPERIMENTS TO BE PERFORMED

Mounting and Use of A Strain Gage

Surface preparation has five component steps:

1) solvent degreasing

2) surface abrasion

3) application of layout lines for gage

4) surface conditioning

5) neutralizing

Note: the gage and terminal is first transferred to a clear glass plate using the tweezers. Figure 2 shows the strain gage and tabs under the tape that is then used to transfer them to (and align them on) the beam. After aligning the gage, carefully lift one side of the tape so the gage is off the surface of the beam. Apply M-Bond 200 catalyst onto the gage and along the tape-beam junction and press the gage onto the beam as described in the manual. Remove the tape.

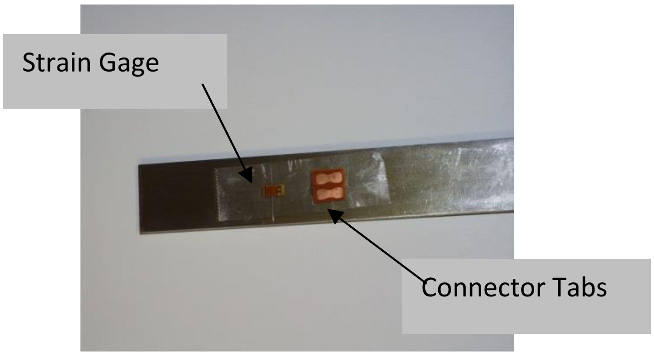


Figure 2: Strain Gage and Tabs under tape on beam

Making Measurements with the Strain Gage

The beam with the strain gage you have just attached will be placed in the Cantilever Flexure Frame to take strain measurements. The arrangement is schematically shown in Figure 3.

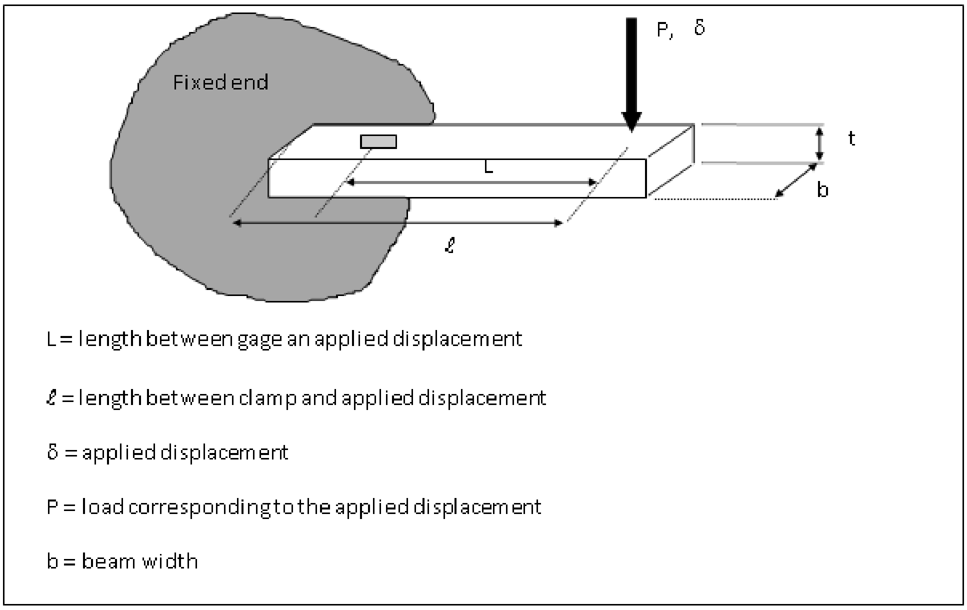


Figure 3. Beam with Strain Gage in Flexure Fixture

An interesting use of the strain gage is in a load cell. Typically load cells are used to measure loads in one direction. In actual set-ups, load cells are calibrated in two ways. The first way is in which the load cell bridge is calibrated by a shunt calibration technique. This is where a known precision resistor is placed across the terminals of the strain gage. A formula determines what the reading should be across the bridge. The value of the output is then interpreted from that reading to give a reading in lb, kg, etc.

The second method of calibration is known as dead weight calibration. This type of calibration is significantly easier and also aids the user in believing the reading produced from the set-up. The load cell (bridge) is balanced from a no-load state. Now increments of weights are added and the potential across the bridge is recorded. The corresponding weight to potential values are recorded and used as a formula for determining unknown loads. This may seem like more physical work, but once again it provides a sense of security in seeing that the loads placed on the cell have a certain conformable value.

The first structure examined in this experiment is the cantilever beam. A beam under bending can be characterized by equation (1).

$$\frac{1}{\rho} = \frac{M}{EI} \tag{1}$$

The radius of curvature is given by equation (2)

$$\frac{1}{\rho} = \frac{d^2y/dx^2}{\left(1+\left(dy/dx\right)^2\right)^{3/2}} \tag{2}$$

where y is the deflection in the y direction at any given point x along the beam. For many problems, the deflection is very small. This means that the denominator can be neglected in most cases. Combining equations (2) and (3) yields.

$$\frac{M}{EI} = \frac{d^2y}{dx^2} \tag{3}$$

This further reduces to a convenient form of the equation for stress in the cantilever beam.

$$\sigma = \frac{My}{I} \tag{4}$$

An equation of the strain in the beam can be written considering any point in the beam. Equation (1) has been derived through fundamentals of mechanics. The parameters in these two equations involve discrete physical values with no inclusion of "mysterious" correction factors. What's significant about this point is that theory will predict (very closely) what we actually see in the loading of the structure. The case of the cantilever beam is a simple introduction to this argument. The same principles and analyses applied to the cantilever beam can be applied to more complicated structures. This results in a compounding of the confirmation of theoretically derived equations through experimentation. Solutions for the remaining structures can be found in most solid mechanics textbooks and therefore no additional information will be provided in this manual for their identification.

Also, there should be some observation about the usability and reliability of the relatively crude instrumentation involved in the experiment. In most cases, strain values differ at most by 5µstrain from the actual values. In most of the experiments here, that relates to much less than an ounce of resolution. In the laboratory most load cells typically fall within 0.5 % error.

5. REPORT

In your laboratory reports must have the followings;

a) Cover

b) A short introduction

c) All the necessary calculations using measured data.

d) Discussion of your results and a conclusion.

6. REFERENCES